Mapping Forest Cover in Madagascar

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Environmental Policy and Institutional Strengthening Indefinite Quantity Contract (EPIQ)

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Executive Summary

In order to meet USAID's need for measurements of forest cover in Madagascar, both long- and short-term strategies are advised: starting with a small pilot program managed by a US agency, then expanding it to include Malagasy institutions and personnel. In the short term, it is advised that remote sensing scientists in the United States conduct a targeted change detection study in four priority zones using state-of-the-art methodology and technology. The results would be a base map of forest cover at the most recent time period available (1999-2000) and measurements of the rates of deforestation over the past two decades.

Three proposals to do this analysis are presented by the USGS, the University of Maryland, and Earth Satellite Corporation. USGS and UMD say that they can complete this work by March 2001 with an estimated cost of about $17,000 (USGS), $100,000 (UMD). Earth Satellite proposes a change detection study using 13 land cover/land use classes and states that the analysis and accuracy assessment can be completed 3-6 months after collecting all necessary data. The cost of their proposal is $102,750 above and beyond the cost of images (about $7,000). Of the three proposals, the USGS is not only the least expensive by far, but also the most practical at this juncture because they are already involved in providing technical expertise in GIS/Remote Sensing to Madagascar and their involvement would be a natural extension of this work.

In the long term there is the need for capacity-building programs to assist Malagasy institutions to monitor environmental changes and to use GIS and remote sensing for decision-making. After completion of the change detection study, the ground-truthing and accuracy assessment will need to be done in Madagascar. This phase of analysis should include forestry and remote sensing scientists from ONE, MEF and FTM in order to introduce the methodology used for the analysis and to determine the location of sample sites on the ground that can be established for future monitoring purposes.

The University of Maryland proposes a three-phase project with 1) the change detection study ($100,000) followed by 2) manager trainings and ground truthing ($100,000), and then 3) developing a program to predict trends in forest loss in the future similar to the one that they have developed in Central Africa. The University has several years of experience with developing and managing capacity-building programs in Francophone countries in collaboration with the Central Africa Regional Project for the Environment. Methodologies for "scaling up" (combining imagery of different scales) are being developed by CARPE and TREES, and there is a possibility to apply these methods to Madagascar in the future.

The USGS also has extensive experience with capacity-building programs in Francophone countries of West Africa, but they have not as yet made a proposal for the second phase of the analysis.

Terms of Reference

Consultant for support to NEAP institutions in development of forest cover indicator for the Tableau de Bord Environnementale, and other forest cover change initiatives

Context

The mid-term review of the National Environmental Action Plan recommended that the evolution of primary habitat cover in Madagascar be a principal indicator for evaluation of success. The key variable to be evaluated will be change in primary forest cover to non-forest (savanna, plantation, agriculture), at a national level but also sampled in USAID priority areas and other key zones. The major cause of forest conversion is small-scale slash-and-burn cultivation. The indicator is also essential for the Tableau de Bord Environnementale, to demonstrate the evolution of the environment in general, and the USAID R4 indicator set, which justifies the USAID intervention in Madagascar.

Data currently available for this indicator is patchy and variably interpreted, and has not been measured for the whole island since 1993-4. USAID has arranged for the purchase of 34 Landsat 7 images of Madagascar for 2000 to permit the re-measurement of the indicator, but in order for this to happen, consensus must be obtained within NEAP institutions and funders about how the indicator should be measured, and how complementary data needed by the different institutions and partners (for instance forest cover at regional or local scales) should be obtained and measured.

Activities

If deemed necessary, visit to US-based institutions (CARPE partners, WWF, CI, WRI, USGS) for synthesis of recent approaches and likely analyses- program and contacts to be agreed with IRG Washington. Evaluate existing data held within Madagascar–especially at ANGAP, MEF, and FTM, in particular the potential for using previous analyses as baselines. Evaluate needs, technical capacity and potential contribution of NEAP institutions and USAID partners likely to need forest cover evolution data- these include the Multi-Donor Secretariat, FTM (Malagasy cartographical institution), ARSIE (NGO of institutions working in GIS), PACT (International NGO working in information management), ANGAP (National Parks Management Association), PAGE (USAID-funded environmental management support project), LDI (USAID-funded support to regional development and environmental management), CFSIGE (Training center for GIS and related activities), WWF, CI, ONE, Ministry of the Environment, Ministry of Water and Forests; and certain potential private sector collaborators. The first step in this activity would be a workshop, implicating these partners, to air the issues and develop a set of basic principles, Evaluate availability, technical potential (for instance in terms of following slash-and burn exploitation at a local scale), price, and need for interpretation of the different spatial data- this should include Landsat 7, FAO imagery, SPOT, Ikonos, and others. Consideration should be made for the need for ground-truthing, complementary aerial photography, etc

Promote agreement among partners for a definition of habitat types for analysis

In discussion with partners, and taking account of current data availability, technical capacity and future budgets, develop simple, robust protocols for: measuring annual rates of forest cover change over the whole of Madagascar, analyzed by habitat type and causes of forest loss, evaluating previous forest cover analyses as potential baselines measuring annual rates of forest cover change on local or regional scales, analyzed according to the needs of users and causes of forest loss integrating the two activities into a complementary whole. At a final joint work session, develop agreements between users of roles and responsibilities.

Key Partners

PAGE will provide secretariat facilities and help with organization of workshops etc. The key contact will be Frank Hawkins. The principal Malagasy partner will be the National Environment Office Environmental Information System project (SIE), but considerable contact will be necessary with ANGAP, Ministry of Water and Forests, FTM, and PACT. USAID will also participate in much of the discussion.

Deliverables

Report detailing proposals for simple, appropriate methodologies for measurement of the USAID R4 indicator, with unit cost estimates for each methodology proposed, and adaptations or developments of this for other partners, with agreements on which institutions will conduct the activities, and who will provide budgets.

Timing

First visit envisaged for 15 days of work after the 10th September 2000, second visit for 10 days of work in November-December 2000.

Profile

Spatial data analyst, with 10 years professional experience in GIS and satellite imagery interpretation, PhD or similar in the subject, fluent technical French, strong teamwork skills, in particular in developing consensus amongst disparate institutions and individuals in difficult technical subjects.

1. Introduction

Forest cover is considered to be a reliable indicator for evaluating the impact of USAID intervention programs for biodiversity conservation. In spite of the fact that the need for accurate information on the extent of forest cover and the rate of change has been recognized for years, there is still no accurate information available for Madagascar. Several attempts have been made to measure rates of change by comparing existing data sets and maps for previous time periods with more recent analyses. The resulting calculated rates have varied sharply because of the lack of a consistent methodology for classifying and interpreting remotely sensed images. The purpose of this study is to find cost-effective and appropriate methods that USAID and its partners in Madagascar can use to monitor environmental changes, specifically changes in forest cover, with remote sensing technology.

In order to accomplish this goal, it is necessary to determine 1) the needs of USAID and the local institutions involved, 2) the technical capacity of these institutions, 3) the institutional issues that need to be considered before a commitment to a long-term capacity building program is made, 4) the availability and usefulness of existing data sets and raw satellite images, and 5) the cost of the proposed analysis and subsequent trainings. We must consider solutions to this problem in both short and long-term time frames. I advocate a step-by-step approach to the problem with each step building on what has come before. In the short term is the need by USAID for data to determine the R4 indicator. In the long term is the need for capacity-building programs to assist Malagasy institutions to monitor environmental changes and to use GIS and remote sensing for decision-making.

Now that Landsat Thematic Mapper (TM) images are available at reasonable prices (and old images will be available for free in the next few months), it is feasible to conduct a change detection analysis for USAID priority zones in a reasonable amount of time and at a reasonable cost. This can solve the short-term needs of USAID for data on the R4 indicator. Achieving the long-term goal of developing methods for producing annual maps of forest cover for the entire country of Madagascar and of developing capacity in local institutions to do this is more difficult and very expensive. This goal requires not only a massive technological effort but also a step-by-step process whereby the needs and goals of the participating institutions should be evaluated and collaboration between these institutions should be encouraged. The technological and institutional questions can be dealt with in the present along parallel tracks, which will converge sometime in the future.

This report begins with a description of the institutions involved followed by a discussion of the institutional issues that are important to consider before embarking on a sustained capacity building program. Following is a section describing the remote sensing data that are available and two proposals for change detection analysis. The final section describes some long-term possibilities for capacity building programs.

2. Needs and Capabilities Assessment of Institutions in Madagascar

USAID and several institutions in Madagascar, including the Ministere de l'Environnement, Ministere d'Eaux et Forets (MEF), l'Association National pour le Gestion des Aires Proteges (ANGAP), and Ministere d'Agriculture, are interested in measuring changes in land cover and land use at local, regional, and national scales. The needs and capabilities of each institution are examined in order to develop a preliminary understanding of what type of land cover information would be useful to them. Although the immediate concern is specifically to map forest, it is important to take into account the need for other types of land cover by other agencies so that a standard methodology can be employed in the beginning that will be able to incorporate these other classes in the future. The following descriptions come from my notes from meetings while I was in Madagascar (Appendix A) and from reports and publications acquired during my visit.

USAID

USAID needs to have quantitative information to assess the impact of their biodiversity conservation programs in Madagascar, and hopes to achieve this by using remote sensing to measure increases and decreases in the rate of forest loss over time. Ideally, they would like to have an accurate and detailed measure of the rate of annual forest loss in conservation priority zones. At the national level, they are interested in developing an integrated system of environmental information with compatible layers of land cover. At the local level, they are interested in monitoring the location of tavy, predicting where forest loss will occur in the future, measuring whether intervention efforts have had an effect, and locating priority habitats for biodiversity conservation. Furthermore, they want the Malagasy government institutions to determine their own needs for indicators, and they would like the analysis to be done by these institutions. They require a preliminary measurement of the rates of forest cover change by March 2001.

Ministry of Environment – ONE and the Tableau de Bord Environnementale

The ONE (Office National pour l'Environnement) is developing a framework for managing natural resources using an ecosystem management approach in partnership with local communities (TBE, Rapport Intermediaire, Sept. 2000 and from a conversation with Director General A of ONE). Their goal is to collect environmental information to use in the decision-making process, promote the capacity to collect and analyze data and information for making decisions, and to present information in a usable form. They are in the process of developing an environmental information system called the Tableau de Bord Environmental (TBE) with the mandate to put in place, coordinate and diffuse environmental information. Five thematic working groups (watersheds, biodiversity, littoral, soil and land cover, and climate change), made up of specialists from government agencies and non-government organizations, are responsible for identifying indicators of environmental change and defining parameters to measure the impacts of this change.

Indicators of land use and land cover change are being developed with the collaboration of FOFIFA, the department of forest research of the research center for rural development. The purpose of indicators is to simplify the analysis of the state of the environment in two ways: they are easy to understand and can be measured on a regular basis. According to the "Rapport Intermediaire" the following general criteria are used to define the indicators: utility and pertinence to policy, analytical accuracy, and measurability. These are summarized by the acronym "SMART (simple, measurable, appropriate, relevant, and timely)" (note from F. Hawkins). In addition, the accuracy of the analysis must be based on sound theoretical foundations and international standards, and can be used in geographic information systems. The data must be accessible at a reasonable price, accompanied by documentation and of known quality, and available at regular intervals.

The themes that use land cover measurements are soil/vegetation cover, biodiversity and littoral (for mangrove forest). Of the total of twenty-six indicators selected for the soil/vegetation cover group, four indicators can be measured using remote sensing: 1) percent surface area of defined vegetation types, 2) loss of vegetation cover by clearing for industry, mining and roads, 3) surface area of forests being exploited, and 4) percent of surface area that is reforested at any given time period. The first indicator would require a land cover map of the entire country, and the other three could be derived from this. The stated limitations to measuring these indicators are: 1) lack of a standard nomenclature, classification systems, or geographic references, 2) the coarse resolution of available data, and 3) the limitations imposed by lack of time and money. MEF is responsible for supplying data to the TBE for these analyses.

MEF – Ministere d'Eaux et Forets

MEF, the ministry responsible for the management of the forests, has the objective of understanding changes that have occurred in forest cover over time. They would like to be able to distinguish secondary forest from dense primary forest and types of secondary forest in three regions: the humid eastern zone, the dry western zone, and the dry southern zone. They propose doing this by mapping forest along the same lines that were used for the Inventoire Ecologique Forestier National (IEFN), which was completed in 1996. The IEFN had the objective of creating a data set that was both precise and accessible and that contained usable quantitative information on the location and distribution of forest types, as well as the diversity, composition, structure, production potential and regeneration potential of these forests. The objective was to establish baseline data with which to monitor changes in forest resources.

The methodology used to create the IEFN is described in a report from MEF in November 1996. The analysis used a total of thirty-three Landsat 5 Thematic Mapper scenes from the following years: 1990 (1), 1992 (3), 1993 (5), and 1994 (24). Photographic prints were made in Belgium using bands 4 (near infrared), 5 (mid-infrared), and either 2 or 3 (for distinguishing shadows). Visual interpretation was done on color prints enlarged to a scale of 1:200 000. The smallest area identified (minimum mapping unit) on the photos was 16 hectares. Field verification was done using a sampling system designed for detailed field measurement of forest properties. The resulting thematic maps were digitized and combined with other cartographic layers. Although not described in the document, anecdotal information from my interviews with various people involved in this effort suggests that some spectral classification of the images was also done, most likely supervised classification using data from sample sites as training sites.

The classification used in this analysis was developed by foresters based on forest management needs with classes distinguished by altitude, density of the canopy, rainfall, leaf type, geomorphic position, and tree species. The classes were selected partly in order to be comparable to data from 1950's aerial photographs. The country was divided into three main forest regions: east, west and south with further division by altitude.

Accessibility of the information for scientists in agencies other than MEF has been problematic, and it is apparent that forest managers who do have access to the digital data set do not make use of it for spatial analysis. This may be because of lack of understanding of how GIS can be used as a tool for forest management and also because few forest managers actually have training in GIS. The sample sites are not being monitored because there are not enough personnel on the ground to accomplish the work.

There is an agreement between MEF and the Institut Geographique et Hydrographique de Madagascar (FTM) regarding the accessibility of the digital data sets used in the creation of these maps: parties seeking access to these data sets need to get permission from MEF and then they can purchase them from FTM. The digital data sets containing land cover information do not seem to be available for purchase, although this situation might change in the future. If these data were to become available, they might be used as reference data in change-detection studies. The first step would be to go back to the original raw satellite images and do a systematic assessment of the interpreted maps in order to have some idea of their accuracy.

Before starting a new phase of work along the lines of the IEFN, a thorough assessment of the need for this type of analysis and some adjustments to the methodology should be made. First, an evaluation of the compatibility of the IEFN data with the TBE criteria should be done. Also, it is important to incorporate methods of spatial analysis using GIS and remote sensing with the detailed descriptions and ground measurements of tree species, etc that are so well developed in the IEFN. Workshops with forest managers to determine their information needs, and trainings to build capacity in using GIS for decision making would greatly improve the usefulness of the next generation of mapping products.

Association Nationale pour la Gestion des Aires Protégées (ANGAP)

ANGAP's mission is to manage a network of 47 protected areas and reserves that have been established to protect biodiversity. First, they must assure that the protected areas actually are adequate to protect a representative group of the natural heritage of Madagascar, and second, they must keep watch over the improvement and the long-term conservation of this network.

ANGAP's contribution to the National Environmental Action Plan is to integrate conservation and development at the regional level. They divide the country into 8 eco-regions based on vegetation and elevation using the classification of Faramalala et al (1996). They use GIS as a tool for management and the measurement of habitats. They need to understand how the forest is changing in different regions, and whether the change is positive or negative for the health of the forest. They have completed studies in several areas, and want to expand these studies to the many small areas that have not yet been done, but do not have enough personnel to do the work. They have a collection of air photos (1:40k scale and 1:60K) for some priority areas, and have used the IEFN to analyze larger areas. They could use Landsat images for detecting general changes in forest cover and to predict overall tendencies, but rely on aerial photographs for their analysis.

ANGAP has benefited from capacity building programs in the past, and has personnel who are very knowledgeable about GIS and remote sensing. Their limitation is that there are too few trained personnel to work in the GIS lab.

Institut Geographique et Hydrographique de Madagascar (FTM)

FTM is the National Mapping Center of Madagascar. They are responsible for providing topographic and cartographic base layers for the country, and were involved in some of the image classification and interpretation for the IEFN. They are in possession of the Landsat images from the 1990's that were provided by foreign donors and used for the IEFN. At present they are working on producing a digital elevation model (DEM) for the entire country from topographic maps at a scale of 1:100k called the "BD-100" which has 50m contour intervals. At present the available topographic base is at a scale of 1:500k (BD-500). FTM has a fully equipped GIS and remote sensing laboratory staffed by knowledgeable personnel. They have the ability to become fully involved in producing land cover data sets for the country if agreements can be reached on how to share data with other government agencies.

They are working in collaboration with the USGS to develop metadata standards in a networked environmental information system. ARSIE is a networking organization that was formed as part of this collaboration, in order to facilitate the management, maintenance, and sharing of data between the different ministries, non-government organizations, private forestry groups, and other partners. ARSIE, as an independent institution, is the logical choice for an agency charged with the equitable distribution of data sets such as land use and land cover maps that will be produced in the future as the result of USAID's long term capacity building program in natural resource management.

Ministere d'Agriculture

The Agriculture Ministry expressed interest in mapping land use using remote sensing and GIS, in order to calculate the surface area of different types of crops.

Ministere de Territoire et Villes (Town and Country Planning)

The Planning Ministry produces cadastral maps from aerial photography purchased from the FTM. These data, which are produced in an internal GIS laboratory, are used for determining property taxes.

3. Institutional Issues

During the needs and capacity assessment phase of this contract, three issues emerged that are important to discuss because they would impact the cost and viability of future mapping and capacity-building programs in Madagascar. These general issues can be addressed by having discussions and workshops prior to initiating the development of national level mapping programs.

1. There appears to be a discrepancy between USAID’s needs for national-level mapping of forest versus non-forest and the needs of the Malagasy ministries concerned with forest management such as Environment, Water/Forests, and ANGAP for more detailed information, and other ministries such as Agriculture and Planning, which have needs for other types of land cover information. This discrepancy should be addressed by getting each agency to prioritize its needs for land cover information and then come to an agreement on these priorities with the other agencies. The preliminary work toward this goal was begun during my visit to Madagascar in October: I met with people from these agencies and discussed their needs for geographic information. This preliminary work should be followed up in a series of workshops where decision makers meet together, and, with the assistance of remote sensing scientists and/or a consultant with general knowledge, come up with priorities for data needs. At a later time, the engineers and specialists from these agencies could be brought together in a workshop to discuss classification schemes and scale issues, but until the agencies have determined their general needs for information in the future, the development of consensus on classification schemes is premature.

2. The government agencies need to agree on data sharing and collaboration. Contracts involving USAID should require collaboration in return for technical assistance, hardware/software purchases, and training.

3. One of the issues inherent in capacity building that has been encountered in other countries is that when personnel are trained in GIS/remote sensing, they are immediately promoted into management and no longer continue to do the technical work. This would not be a problem, and actually could become an asset, if USAID and its counterparts could make a long-term commitment to supporting ongoing training programs that insure a steady supply of technical expertise.

4. Existing Maps and Data Sets

Several analyses of forest cover have been made using remotely sensed imagery from the 1950’s to the early 1990’s. Two of these are at a national scale and could potentially be used as reference data on forest cover. Although these studies were the result of excellent and painstaking work by respected scientists, they used different classification schemes for the vegetation and different methodologies for processing and interpreting the photos and images. I was unable to find detailed descriptions of the methods used in most of these studies, and there appears to have been no post-interpretation field verification and accuracy assessment of the resulting data sets. Although general trends in forest cover change over time can be ascertained from these maps, no more accurate analysis can be performed unless they are further evaluated.

- Faramalala (1995) vegetation map available as hard copy print at a scale of 1:1 million; based on interpretation of Landsat MSS images from 1972-1979. This could be a valuable reference data collection on forest cover if the digital map could be independently evaluated using the original images.

- National Forest Inventory (IEFN, 1999): forest cover based on Landsat TM images from the early 1990’s; hard-copy maps are available at various scales; digital data (vector files) derived from the images might be available for use. This data set needs to be independently evaluated by comparing it with a spectral analysis and interpretation of the original images. If it is reasonably accurate, then the polygons can be used as a reference against which to measure change with more recent satellite imagery. Anecdotal evidence as to the quality of the mapping suggests that the interpretation of satellite imagery was executed carefully for the most part, but that there are major inaccuracies in the final product. No quantitative accuracy assessment was conducted.

- Global data sets available from coarse resolution (1.1 km and 7.6 km AVHRR) satellite imagery: spatial resolution is considered by USAID as too coarse for measuring the R4 indicator. These data, available from the USGS, might be useful as tools for monitoring general trends in forest cover change since they are readily available, have excellent temporal resolution (every ten days) and are almost cloud-free (because each image is a composite of ten days of images, clouds can be filtered out).

- Two change-detection studies have been attempted using previously existing data. The study by Dufils using photos from 1950 and 1991 and TM from 1995 and the study by Horning, which used Landsat TM imagery from the 1990’s. The first succeeded in recognizing trends in the rates of change while the second attempted to accurately measure the rate of change for several target zones around protected areas. Problems were encountered in both studies with comparing data from two time periods because of the different methods used to do the interpretation.

Recommendation

Regardless of whether the GIS data are available in digital format or hard copy, because of the incompatibility of the classification schemes and methods of interpretation, they should not be used as digital overlays in a GIS to produce change polygons unless there is careful re-interpretation and hand digitizing to correct errors. They can be used as an analogue source of information to reinterpret the old satellite images, which can then form a reference from which to measure change.

5. Raw Satellite Imagery

One of the main challenges to measuring changes in forest cover in Madagascar over the past decade has been the unavailability of raw digital data that were acquired in the early 1990's for the National Forest Inventory. According to FTM, because of copyright laws, Landsat 5 Thematic Mapper images from 1993-94 that were used to interpret forest cover cannot be shared with other agencies in Madagascar. In addition, the vector files derived from the inventory itself (the "IEFN") are not readily available in digital format, although printed maps are available at scales of 1:250,000.

Following is a list of available air photos and satellite imagery:

- 1950 air photos held by FTM (used as base for 1:50 k and 1:100k topographic maps and a study of vegetation cover by Humbert and Darne, 1965).

- Landsat TM and MSS from late 1970's to late 1980's: The mosaic of Madagascar that was done by USGS used some images from this time period. Inquiries to USGS have not yielded information in this regard.

- Landsat TM from the early nineties held by FTM; copyright restrictions keep them from being shared with other agencies. These images were not furnished directly by US agencies, so it requires further discussion with FTM and its partners to determine the status of these images.

- Landsat TM from late 1980's to early 1990's: full coverage can be purchased from Earth Satellite Corporation for about $6,000.

- Landsat TM images from 1984 to 1995 are available for purchase on the USGS Earthexplorer web site for $425 for the first scene (systematic corrected TM) and $200 for each additional scene. Total coverage of Madagascar (34 scenes) would cost about $7025. These scenes are beginning to come available at no cost, although they may not be accessible until March 2001.

- 2000 Landsat ETM+ is being purchased by the USGS: as of early December, 2000, 23 out of a total of 34 scenes have been acquired and they are in the process of being re-projected. They will be available in the near future. Copies of these scenes will be made available on request and the USGS will give out about 4 copies of each (USAID and other agencies in Madagascar).

Recommendation

Obtain old Landsat 4 and 5 images from the 1980’s and 1990’s and conduct a change-detection analysis on those images that are available for the priority zones and that have enough cloud-free area to work with. A listing of Landsat images that have minimal cloud cover and that cover the four priority zones is found in Appendix B.

6. Proposals for Methodologies and Cost Estimates for Measuring the R4 Indicator

In order to meet the immediate needs of USAID to have an accurate measure of the rates of forest cover loss, the best alternative is to contract with an agent in the United States to do a change-detection analysis from Landsat imagery from the 1980’s, 1990’s and 2000 in four areas of strategic interest to USAID. Three agencies have been contacted and have agreed that this is the best alternative given the deadline of March 2001. The agencies that submitted preliminary proposals to do the analysis are the USGS, the University of Maryland and Earth Satellite Corporation. The zones of highest priority to USAID that could be analyzed in the next several months are the following: 1) northern sector around Ankarafantsika, 2) Zahamena-Mantadia corridor, 3) Fianarantsoa corridor, and 4) Anosy region. The proposals that follow are preliminary in nature and are quoted from emails received from Jim Rowland (USGS) and Nadine LaPorte (UMD). The estimates of the size of the study area are based on a sketch map provided by Frank Hawkins. A more accurate map of the polygons that need to be studied should be provided to the potential contractors so that they can refine their time/cost estimates and compare them with the locations of available images.

United States Geological Survey:

The USGS proposes to conduct a forest cover change detection analysis of the four priority zones using images from two or three time periods (depending on availability) and interpreting three classes (primary forest, non-forest, and other/degraded/secondary/mixed forest).

Methodology: (from an email from Jim Rowland)

1. Image-to-image co-registration for all time periods;

2. Mosaicing of registered scenes (dependent upon acquisition date);

3. Forest cover interpretation in three classes for most recent date; (primary forest, non-forest, other [mixed, secondary, degraded forest]); hybrid spectral classification methods including unsupervised with seeded training sites; post-classification manual editing, and edge-matching of results, if not previously mosaiced;

4. Automated spectral change detection for TM-to-TM scenes (e.g., change vector analysis providing magnitude and direction of change) to assist in manual detection, delineation and interpretation of forest cover change;

5. Manual detection, delineation and interpretation of forest cover change via on-screen digitizing;

6. Derivation of statistics on forest change;

7. Production of maps depicting forest change.

They estimate the following level of effort (LOE) to update a current forest cover map (2 or 3 classes), for the four (4) regions previously discussed (approximately 10 scenes required, with interpretation for an area equivalent to approximately 5–6 full Landsat scenes):

- 1 week—load, import data (new year, previous year);

- 1 week – co-register, mosaic, window data;

- 1 week—classify/interpret data (cluster, change vector analysis, on-screen digitizing);

- 2 weeks–post-classification edit, map production, statistics derivation (area old, area new, %change, change matrix).

This adds up to approximately 5 weeks of work, although it may be feasible to complete the work in 4 weeks of WORK time (not necessarily calendar time).

The above LOE estimate does NOT include the following:

- time researching/ordering images;

- validation, technology transfer;

- report writing.

Cost: $13,000–$17,000

In addition to the cost of Landsat images, which is about **$4,450** for twenty images (about ten images for two time periods). Since the USGS is purchasing one set of images (those from Landsat 7) under another agreement, it is not necessary to include the cost of these here. The overall cost would be lower and the time required would be shorter if only two classes (forest and non-forest) were used, or if fewer images were available for analysis.

University of Maryland

The University of Maryland proposes to use the "NASA Landsat Pathfinder Methodology" adapted to the Landsat images available for Madagascar to conduct change detection analysis for the four priority zones.

They use PCI EASI/PACE software to perform the image processing in the following steps.

1. Co-register images from different dates for same WRS path/row tile

2. Unsupervised clustering using raw data bands

3. Bitmap mask is created of the output clusters that are confused between two or more classes and an additional unsupervised clustering is run on the data under this mask

4. Display and compare the output of the unsupervised clustering with the raw data bands. This process is repeated until a satisfactory discrimination is achieved. The ISOCLUS output clusters are then assigned to classes.

5. Editing/Quality control of classified image by hand . Common corrections include: aggregating clouds and heavy haze into the cloud class; correcting computerized misclassifications between water, cloud shadow, and burn scars in non-forest, all of which have very similar spectral signatures; correcting for misclassification between deforestation and non-forest, as well as topographic effects.

6. Country product creation: converted to the ARC/Info Grid format and registered to adjacent tiles and to their correct location on Earth

Cost: about $100,000.

A more detailed description of the methodology used by the University of Maryland can be found in Appendix D. A detailed proposal specific to Madagascar will be forthcoming.

Earth Satellite Corporation

Earth Satellite proposes to create a product with 13 land cover/land use classes using their established methodology as follows:

The basic outline of this project will be to select Landsat 7 ETM+ scenes, orthorectify them to the GeoCover Ortho image base, perform CCA, update the land cover for only those areas that have changed, and then recreate the entire suite of GeoCover LC products, including a Bivariate

Raster Product that identifies both the older and more recent land cover for each pixel. This process will also be repeated to take the 1970's era MSS data, perform CCA, and then producing the land cover and land cover change from the 1970's to the 1990's era GeoCover LC product.

1. Image Selection

2. Image Orthorectification – the selected images will be semi-automatically orthorectified to EarthSat's GeoCover Ortho database using EarthSat's IPS software

3. Change Analysis – CCA will be used to identify changes between the 1990's era TM scene and the new Landsat 7 TM scene. CCA will correlate the 1990 era ungrouped thematic file (240 spectral classes) to the 6 multispectral bands of the recent Landsat 7 scene and will correlate the 1990 6 multispectral bands to a ungrouped thematic file (240 spectral classes) of the recent Landsat 7 scenes. These images will be evaluated to determine if the change that has been detected is appropriate and how much change must occur in an image to trigger land cover. This process will be repeated with a change analysis of the 1970's MSS to the 1990's TM data.

4. Semi-Automated Land Cover Updating – EarthSat has a semi-automated process that is then used to edit the CCA thematic change file to determine the land cover that has been highlighted by the change analysis. EarthSat's trained image interpreters review both original images to determine the land cover in areas of change

5. Create Bivariate Land Cover Classification – the edited change file derived from the newer TM data and the older MSS data are then compared to the GeoCover LC data. These data are merged to create a land cover change product.

Cost: of conducting change detection for the four priority zones using this methodology is **$102,750** (without purchasing the images) and **$116,350** including the images.

A more detailed description of the methodology used by EarthSat and cost estimates for the proposed studies can be found in Appendix E.

7. Adaptations or Developments of Methodologies for Other Partners: Long Term Capacity Building

The post-analysis validation phase provides an excellent opportunity to involve interested Malagasy government agencies such as MEF, Ministry of the Environment, and FTM to participate in evaluating the interpretation that was done by the USGS. This phase would be the first step in a long-term capacity-building program in Madagascar, which would familiarize the local engineers with the techniques and standards of spectral analysis and change detection used by the USGS. Accuracy assessment is a large undertaking and must be well planned. It should include statistically valid sampling parameters. Existing maps could be used as reference data, although this may cause problems since the classification schemes are different and the accuracy of these reference maps is unknown. The inventory data from the IEFN sample plots may be preferable as a reference data set, and these sample areas could be updated if they are located in such a way as to provide statistically valid samples of the mapping units. Additionally, new sampling locations could be established. A comprehensive plan and budget for the accuracy assessment should be worked out ahead of time. This can be accomplished while the change-detection analysis is being undertaken and can involve Malagasy institutions, especially in the discussion of establishing sampling sites.

Developing the capacity in Madagascar to produce accurate and detailed maps of forest and other vegetation cover using techniques that meet international standards is feasible if donors are willing to make a long-term commitment and provide adequate funding to accomplish it. However, the scope of the project and the needs of decision-makers require further discussion in order to be realistic. In the United States, the Forest Service has developed the most sophisticated and integrated system in the world for monitoring forests using remotely sensed data. The cost that they estimate for mapping forest for one time period across the country is $1 per acre. Extrapolated to Madagascar, this cost is about $247 per square kilometer. This works out to about $150 million for mapping the entire country. This figure is cited here as an indicator of the amount of effort that is required to develop a truly comprehensive and integrated program using a “scaling up” system of air photographs and satellite imagery. The cost of this sophisticated enterprise is the best argument for starting to build a program slowly with small strategic sampling leading to larger and more ambitious mapping projects in the future. While the program in Madagascar builds over the next few years, new techniques, data, and software are now in the process of being developed that will make mapping easier and cheaper. In the meantime, USAID could acquire the annual data that it needs to measure indicators of its programs’ effectiveness while including local partners in the analysis.

A good example of a long-term program in mapping forest that contains a large capacity-building component is the Central Africa Regional Project for the Environment (CARPE) which has involved USAID in more than a decade of collaborative research by scientists in several institutions and NGO’s. Fortunately, this project can provide the expertise and data to launch a similar program in Madagascar. The US Forest Service Office of International Programs, in collaboration with the University of Maryland, has several years of experience developing trainings for forest managers and remote sensing technicians in the Francophone countries of central Africa (Cameroon, Gabon, Central African Republic). A list of GIS/remote sensing training courses offered by the Forest Service Remote Sensing Applications Center in Salt Lake City, Utah is given in Appendix C. They also have ongoing exchange programs with universities in these countries and have supported several exchange students at the University of Maryland. They have developed a system for using satellite imagery of different resolutions to measure the change over the whole region. The USGS has also developed programs for mapping land cover in Francophone western Africa (Senegal) using remotely sensed data of different resolutions. Drawing from the vast expertise and experience of these institutions is the best way to develop a program for Madagascar. Further discussion with these groups could be very fruitful in developing a strategic plan for how to proceed in Madagascar.

The University of Maryland proposes the following for Phase 2

Phase 2: (May 2001-December 2001)

The land cover change methodology and other remote sensing derived products (vegetation maps, etc) are presented to national institutions during a USAID workshop (1 week at Management level). Then the following (week 2-3) the technical staff is trained to implement and validate results (field ground truthing). The methodology might be slightly changed during the technical workshop to address specific needs or limitations identified by nationals. Also, methods on extrapolating deforestation rates at national level will be discussed with management and technical staff. (Leaders: workshop logistic (USAID), workshop organization: USAID-USGS-USFS-UMD-?)

Estimated cost: $100,000

Phase 3: (January 2001- June 2002)

Predicting deforestation trends.

Rates of deforestation estimated by national institutions (Forest Service etc) are integrated in a spatial model allowing prediction of deforestation rates. The GIS model inputs will include satellite imagery, socio-economic, macro-economic, and anthropological information. A preliminary model would be developed by UMD in collaboration with national institution and will be discussed during another workshop in Madagascar.

Estimated cost UMD: $ 100,000 + workshop: $100,000

8. Recommended Timetable of Activities

Following is a suggested timetable for obtaining the data needed by USAID for the R4 indicator while at the same launching the first steps toward long-term capacity building:

January-March, 2001:

1. USGS or the University of Maryland does change detection analysis for R4 indicator; provides estimates on rates of change of forest cover over two decades 1980-2000 by the end of March.

2. Workshop with Malagasy partners to discuss priorities for future mapping: a) how remote sensing can be used for decision making, b) how data can be shared between agencies or whether it needs to be c) discussions on collaboration in the production of data sets and sharing the end products

3. Plan budget and procedures for accuracy assessment involving Malagasy partners; discuss with MEF an overall sampling system for the four USAID priority zones.

April-June 2001:

1. Accuracy assessment and ground truthing by Malagasy partners, particularly MEF

2. Workshops with forest managers and decision makers on using remote sensing for management of forests;

3. Begin developing a strategic plan for long-term capacity building program with USGS, US Forest Service, and University of Maryland.

July-October, 2001:

1. Workshop using finalized products to discuss how the data can be useful to managers and decision makers;

2. Begin technical trainings of GIS engineers using hardware and software and methodology developed by USGS to map land cover; each agency decides what it wants to map.

By the end of 2001 expect to be able to use coarser resolution imagery from Terra satellite called MODIS to assess R4 indicator.

Appendix A

Contacts and Meeting Schedule

September 12	Briefing by Frank Hawkins followed by USAID briefing held at PAGE; Greg Overton, Adele Rahelimihajandralambo, Frank Hawkins, Luciano Andriamaro, Philip DeCosse.
September 13	DG du Ministere de l'Environnement, M. Georges Rafomanana; meeting at ONE with M. Herisoa Razafinjato
September 15	Meeting at ONE with DGA M. Jean Chrysostome Rakotoary; Universite d'Antananarivo, EESA Forets, Dr. Gabrielle L. Rajoelison.
September 18	DG de Ministere D'Eaux et Forets. Mme. Fleurette Andriatsilavo
September 19	PACT, M. Jean Michel Dufils; DG CFSIGE, M. Joseph Amade; Universite d'Antananarivo, EESA Forets, Dr. Mino Razafindramanga.
September 20	Ministere de l'Amenagement du Territoire et de la Ville, M. Passou Ratsitoarison; meeting with the engineers and GIS technicians at MEF with M. Andre Rakotoarivelo and Voahirana Andriatsalama.
September 21	Attended a meeting of MEF collaborators at the office of the World Bank; meeting with Adele R. of USAID.
September 22	DG of FTM, M. Narizo M. Rahaingoalison followed by a technical tour with M. Marc Ramananirina Ranjalahy and discussion with Mssrs. Jean Desire Rajaonarison and Nicolas Lambert of ARSIE.
September 25	DG of OMAPI (Office Malgache de la Propriete Industrielle) Mme Lalao Raketamanga; M. Benoit deLaitte of Conservation International (at MEF); technical tour of CFSIGE with M. Frank
September 28	Meeting with representatives of ONE and MEF at PAGE; meeting with DG of ANGAP, Dr. Faramalala and M. Alain Ramaherison.
September 29	Debriefing at USAID office.
October 9	Meeting with Lisa Gaylord (USAID), Phillipe DeCosse (PAGE), Frank Hawkins (PAGE), and Jean Michel Dufils (PACT)

October 26	Meeting with David Cunningham and Richard Borda of Earth Satellite Corporation
November 16	Meeting with Melissa Othman, Paul Maas, and Henry Lakowski (US Forest Service) and Nadine LaPorte (University of Maryland).
Several dates	Telephone and email conversations with Jim Rowland (USGS), Nadine LaPorte (U. Maryland), Richard Borda (Earthsat), Melissa Othman (USFS).

Appendix B

Table of Available Landsat Imagery for Madagascar

Table of available Landsat Imagery for Madagascar

Path	Row	1984	1985	1985	1987	1988	1989	1990-1991	1992-1994
157	71								
158	69								
158	70								
158	71								
158	72								4/8/93 ES
158	73	11/25/84						10/25/90 ES	
158	74	11/25/84					9/20/89 ES		
158	75	11/25/84				3/17/88	9/20/89 ES		
158	76					3/17/88	9/20/89 ES		
158	77	11/25/84				3/17/88		7/24/91 ES	
159	68		1/19/85						
159	69	6/25/84		3/8/85	7/4/87				6/21/94 ES
159	70	6/25/84		3/8/85	6/18/87	3/8/88		6/29/91 ES	
159	74	6/25/84		3/8/85					4/28/92 ES
159	75	6/25/84	1/19//85	3/8/85				4/7/90 ES	
159	76	6/25/84	1/19//85	3/8/85					4/15/93 ES
159	77	6/25/84	1/19//85	3/8/85					4/15/93 ES

Path	Row	1994	1994	1994	1994	1995	1995	1996	1999-2000
157	71	10/13/94		11/30/94			2/18/95 ES		
158	69	9/2/94 ES		11/21/94		1/24/95	3/29/95		
158	70			11/21/94		1/24/95	3/29/95	8/22/96 ES	
158	71			11/21/94		1/24/95	3/29/95	8/22/96 ES	
158	72			11/21/94					
158	73			11/21/94					4/19/00
158	74			11/21/94			3/29/95		
158	75								11/11/99
158	76								
158	77								11/11/99
159	68	8/24/94 ES	10/27/94	11/28/94		1/15/95			
159	69	10/11/94	10/27/94	11/28/94	12/14/94	1/15/95			6/13/00
159	70		10/27/94		12/14/94				
159	74	10/11/94	10/27/94		12/14/94				10/17/99
159	75	10/11/94			12/14/94				10/17/99
159	76								10/17/99
159	77								10/17/99

Notes:

1999-2000 images are Landsat 7 ETM+ that have been purchased by USGS.

ES = images available for purchase from Earth Satellite Corporation.

All others listed are available for purchase on the EROS Data Center web site and have been selected based on quality and usefulness (lack of or minimal cloud cover in the areas of interest).

Appendix C

Courses offered by the US Forest Service, Remote Sensing Applications Center in Salt Lake City, Utah

Integrating Geospatial Technologies (3 days)

Basic Aerial Photo Use (4 days)

Advanced Aerial Photo Application Topics (4 days)

Aerial Video & Digital Camera Applications (4 days)

Global Positioning System Applications (4 days)

Basic Cartography for GIS Users (3 days)

Remote Sensing Applications in Archeology & Cultural Resources

Management (5 days)

Remote Sensing Applications in Pest Detection & Monitoring (3 days)

Basic Digital Image Processing* (4 days)

Advanced Digital Image Processing: Change Detection* (3 days)

Remote Sensing Awareness CD (1/2 to 2 days, self –paced)

Appendix D

University of Maryland Method for Change Detection

The following description is taken from the UMD web site (http://www.geog.umd.edu/tropical/method.html):

Digital image processing in conjunction with spatial analysis in a Geographic Information System is effective means for quantifying deforestation we use high resolution Landsat because it yields much better precision than AVHRR-based analyses. Automated classification and manual editing has been found to provide significantly faster and more accurate than hand digitizing alone. Further, it would be very difficult, if not impossible, to reproduce the automated classification level of detail by hand digitizing alone. The approach adopted in processing Landsat data is to exploit automated methods to the fullest extent possible but then to use the skills of the human interpreter to improve the classification.

Details of this methodology as carried out by the University of Maryland are described in the following paragraphs:

Processing the raw satellite data into our vegetation classes

The University of Maryland Landsat Pathfinder Project uses multi-spectral/multi-temporal data sets to produce accurate, consistent and rapid classification. Under our approach we co register images from different dates for the same WRS path/row tile. We then use the spectral bands for both image dates as input for unsupervised clustering. The resultant clusters represent both cover types, which remain unchanged between the dates and areas, which have changed. This procedure has been found reliable in distinguishing between changes due to phenological change from those due to more permanent changes associated, for example, with deforestation or regrowth.

We use PCI's EASI/PACE software for image processing and co registration. GCPWorks, a module of EASI/PACE, is used to co register the images. We currently use analyst identified control points for co registration. While we are testing automatic procedures, these methods have not yet yielded consistent sub-pixel registration we obtainable from our control points identified by image analysts.

Our unsupervised clustering algorithm uses the EASI/PACE histogram clustering process Isodata clustering (ISOCLUS). We use ImageWorks, a module of EASI/PACE, to display and compare the output of the ISOCLUS with the raw data bands. The output clusters are color coded using a pseudocolor table(PCT). Usually the initial clustering will not be enough to completely distinguish between classes. A bitmap mask is created of the output clusters that are confused between two or more classes and an additional ISOCLUS is run on the data under this mask. This process is repeated until a satisfactory discrimination is achieved. The ISOCLUS output clusters are then assigned to our classes. (Pan Amazon; forest, deforestation, revegetation, non-forest vegetation, undifferentiated unforested, cloud/cloud shadow, and water. Central Africa; forest, degraded forest, non-forest, cloud/cloud shadow, and water.) These steps produce a classification where almost all the polygons of the desired land cover types are identified.

Editing/Quality control of classified image

While the iterative ISOCLUS procedure produces a much more accurate product then previous procedures using supervised classification and hand editing of a vector product, there are usually still small corrections that need to be made by hand.

Currently, edits are done directly on the raster product. The raster product is vectorized and overlaid directly onto the raw image data in the ImageWorks image handler. This allows the image processor to use all the image enhancement tools needed to appropriately interpret the image as well as compare the output product to the raw image data from both dates being considered in the classification. If the image analysts finds errors in the classification they draw bitmaps over that area and either edit the output product using a modeling statement to reassign the classes or run an additional ISOCLUS on the area. This decision is dependent on the complexity and size of a region. More difficult areas have the clustering procedure run on them again.

Common corrections include: aggregating clouds and heavy haze into the cloud class; correcting computerized misclassifications between water, cloud shadow, and burn scars in non-forest, all of which have very similar spectral signatures; correcting for misclassification between deforestation and non-forest, as well as topographic effects.

A final assessment is carried out by the laboratory manager. This helps ensures consistency of results. Once the lab manager feels a coverage is complete, the project PI's and personnel who have visited the field review the finished coverage based on their field experience. Any questions about interpretation that cannot be answered during this process are recorded in the IMS, and in-country experts are contacted for advice. A mechanism is firmly in place where, as auxiliary information is made available, the coverage can be improved.

The current system is producing a consistent and accurate product as is demonstrated by the fact that little, or no, thematic corrections are necessary when adjacent coverages are joined together.

Country product creation

Once the images are finished, they need to be converted to the ARC/Info Grid format and registered to adjacent tiles and to their correct location on Earth. Until this point, they are in the coordinate system provided by the satellite meta data, and while this is close, it is not correct. We are using the Digital Chart of the World's country boundaries for this registration. The DCW is a 1:1,000,000 scale vector base map of the world. It was originally created by the United States Defense Mapping Agency (DMA) and was adapted for use with Arc/Info software. The primary source for the DCW is the DMA Operation Navigation Chart (ONC) series.

Each country border coverage is moved to the corresponding border in DCW. This can be performed accurately in most locations because the border follows rivers that are easily distinguished in the images. The scenes are also moved so that features match up in adjacent scenes. The registration process involves affined moves and rotations of the complete scenes. No rubber sheeting is being performed on the scenes. Since all images for a WRS path/row tile will be co registered to the same image this georegistration step needs to be done only once. All subsequent images can be transformed to the location of the 'base' georegistered grid.

In some locations country boundaries may be locally systematically displaced from topographic features such as rivers apparently as a result of local errors in the DCW. In such cases the topographic features are used as the boundary.

Once the grids are georegistered, they are merged together in ARC/Info. The grids are merged so as to maximize the usage of clear, cloud-free imagery.

Appendix E

EarthSat's Land Cover Change Analysis

Earth Satellite Corporation (EarthSat) is pleased to provide this proposal to provide land cover change services for Madagascar. Throughout it's 30-year history EarthSat has developed new products and processing techniques to exploit remotely sensed data. EarthSat is a leader in the application of commercial and civil satellite imagery. This proposal takes advantage of EarthSat's GeoCover family of products (GeoCover Ortho, and GeoCover LC) as well as a patented (U.S. patent No.: 5,719,949) change detection technique called Cross Correlation Analysis (CCA). EarthSat has spent many years and thousands of hours developing these products and techniques and is pleased to offer these products and techniques (GeoCover Ortho, GeoCover LC, and CCA) to provide rapid update and change analysis products.

Introduction to CCA

EarthSat originally developed CCA as a technique to determine areas where existing maps were out-of-date based upon change detection of satellite imagery. The original application of this technique was used to assist the United States Fish and Wildlife Service National Wetlands Inventory (NWI) program. Since the late 1970's NWI has been responsible for mapping the nation's wetland resources. To accomplish this task, NWI relied on aerial photography acquired in the middle to late 1970's and early 1980's by USGS' National High Altitude Photography Program (NHAP). Consequently, many of the wetland maps were produced from 10 to 20 year old aerial photographs. As is the case in many mapping projects, it was soon realized that many of the maps were of questionable value due to subsequent changes (both natural and human induced) in the wetlands. With traditional methodology, the only way to provide updated wetlands information would be to repeat the entire study using new aerial photography, such an effort is not only cost-prohibitive, it is also unlikely to keep pace with the rapid changes in some regions of the country. While attempts had been made to reduce costs by automating wetland classification with satellite imagery, the results failed to meet NWI's minimum mapping unit and accuracy requirements. CCA addresses both cost and accuracy concerns: It uses the synoptic strengths of the satellite image in conjunction with the accuracy of the NWI maps to locate change. Then, only the maps that are identified as out of date require new aerial photography, photo-interpretation and digitization. This solution conserves resources and maintains NWI's minimum mapping unit and accuracy standards in a most cost-effective way.

EarthSat has expanded CCA's original role by implementing it as a key component in land cover change analysis. CCA and it's inverse implementation (inverse CCA) have been added to EarthSat's land cover analysis and updating procedures. By using change detection in the land cover updating helps reduce the compounding of errors associated with generating separate land cover analysis for each date and then combining the results. These techniques make the determination of land cover change from existing land cover products extremely efficient, accurate, and economical. EarthSat has used this process to update over 300 TM images of land cover in Northeast Africa for NASA as well as a number of other land cover change studies throughout the world.

Processing Steps

A brief description of the process EarthSat's CCA land cover updating process is described below. The processing will be completed using EarthSat's software (for orthorectification and vectorization) and ERDAS IMAGINE (for CCA and creating the various required raster products). Many of the steps utilize ERDAS IMAGINE Models that were created by EarthSat specifically for the production of land cover and land cover change products.

The basic outline of this project will be to select Landsat 7 TM scenes, orthorectify them to the GeoCover Ortho image base, perform CCA, update the land cover for only those areas that have changed, and then recreate the entire suite of GeoCover LC products, including a Bivariate Raster Product that identifies both the older and more recent land cover for each pixel. This process will also be repeated to take the 1970's era MSS data, perform CCA, and then producing the land cover and land cover change from the 1970's to the 1990's era GeoCover LC product.

1. Image Selection –One of the strengths of CCA is that if overcomes many of the problems associated with traditional change detection techniques, including seasonal variation in imagery. However, it is recommended that the scenes be selected during the growing season. Another strength of CCA is that it also works independent of the resolution of the imagery selected, and has been used to compute change between MSS and TM data.

2. Image Orthorectification – the selected images will be semi-automatically orthorectified to EarthSat's GeoCover Ortho database using EarthSat's IPS software. EarthSat's IPS software uses the satellite ephemeris data to automatically place the scene in the correct path/row, spatial autocorrelation techniques will then be used to select conjugate points in each scene. This process will produce an orthorectified image that will be less than a pixel and a half positional error which is very important to minimize false changes caused by poor registration.

3. Change Analysis – CCA will be used to identify changes between the 1990's era TM scene and the new Landsat 7 TM scene. CCA will correlate the 1990 era ungrouped thematic file (240 spectral classes) to the 6 multispectral bands of the recent Landsat 7 scene and will correlate the 1990 6 multispectral bands to a ungrouped thematic file (240

spectral classes) of the recent Landsat 7 scenes. Each correlation generates a separate Z-statistics file. The maximum value of each Z-statistic file will be used. This analysis results in a thematic image of Z-statistics with values ranging from 0 to 60,000. The higher the value, the more likely the land cover has changed. These images will be evaluated to determine if the change that has been detected is appropriate and how much change must occur in an image to trigger land cover. This process will be repeated with a change analysis of the 1970's MSS to the 1990's TM data.

4. Semi-Automated Land Cover Updating – EarthSat has a semi-automated process that is then used to edit the CCA thematic change file to determine the land cover that has been highlighted by the change analysis. EarthSat's trained image interpreters review both original images to determine the land cover in areas of change.

5. Create Bivariate Land Cover Classification – the edited change file derived from the newer TM data and the older MSS data are then compared to the GeoCover LC data. These data are merged to create a land cover change product. (This is the product that was produced for Phase I of NASA's Commercial Data Purchase for over 300 scenes in Northeast Africa.) This change file is extremely useful for a variety of environmental applications and will be provided in an 8-bit ERDAS IMAGINE file. The bivariate land cover change file can be easily manipulated to depict land cover from either time period (mid 1990's or 2000) or for the change from one to the other. The table below shows the class values in the bivariate land cover change file. Note: by coloring this file by columns, 1990-2000 land cover will be shown. (e.g. if values 1, 14, 27, 40, 53, 66, 79, 92, 105, 118, 131, 144, 157, 170, are all colored green they would indicate deciduous forest in 1990-2000. Similarly, if values 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 were colored green, they would indicate deciduous forest cover in 1990. Finally, if value 7 were highlighted in red, the red areas would indicate forests that had been converted to cropland.) A three way composite showing change from 1970 to 1990 to 2000 will also be created.

GeoCover LC Landcover Change Bivariate Codes			1999–2000 TM Classes												
			Forest–Deciduous	Forest – Evergreen	Scrub/Brush	Grassland	Barren Ground	Built-Up Area	Cropland	Agriculture – Rice	Wetland – Permanent Herb	Wetland–Mangrove	Water	Ice/Snow	Clouds/Shadow/Data Drops
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1990 TM Classes	**Forest–Deciduous**	**1**	1	2	3	4	5	6	7	8	9	10	11	12	13
	Forest – Evergreen	**2**	14	15	16	17	18	19	20	21	22	23	24	25	26
	Scrub/Brush	**3**	27	28	29	30	31	32	33	34	35	36	37	38	39
	Grassland	**4**	40	41	42	43	44	45	46	47	48	49	50	51	52
	Barren Ground	**5**	53	54	55	56	57	58	59	60	61	62	63	64	65
	Built-Up Area	**6**	66	67	68	69	70	71	72	73	74	75	76	77	78
	Cropland	**7**	79	80	81	82	83	84	85	86	87	88	89	90	91
	Agriculture – Rice	**8**	92	93	94	95	96	97	98	99	100	101	102	103	104
	Wetland – Permanent Herb	**9**	105	106	107	108	109	110	111	112	113	114	115	116	117
	Wetland–Mangrove	**10**	118	119	120	121	122	123	124	125	126	127	128	129	130
	Water	**11**	131	132	133	134	135	136	137	138	139	140	141	142	143
	Snow Field/Ice Field	**12**	144	145	146	147	148	149	150	151	152	153	154	155	156
	Cloud/Shadow/No Data	**13**	157	158	159	160	161	162	163	164	165	166	167	168	169
	No TM Data	**14**	170	171	172	173	174	175	176	177	178	179	180	181	182

Landcover Categories

The landcover categories in the GeoCover LC product follow closely to those defined by Anderson et al. in his 1976 publication, “A land use and landcover classification system for use with remote sensor data" (U.S.G.S. Professional Paper 964). Brief descriptions of the 13-landcover categories are shown below:

Brief Description of Landcover Classes

Category Number	Category Title	Category Description
1	**Forest, Deciduous**	Woody vegetation > 3 meters (10 ft) in height that lose leaves periodically due to changing seasons or drought. Canopy closure must be >35% (<35% = Category 3). Also included in this category are areas commonly referenced as "swamp" or forested wetland if dominated by a deciduous canopy.
2	**Forest, Evergreen**	Woody vegetation > 3 meters (10 ft) in height that retain their leaves throughout seasons. Evergreen includes both needle leaf and broad leaf species. Some tree plantations may be included in this class. Canopy closure must be >35% (<35% = Category 3)
3	**Scrub/Shrub**	Woody vegetation less than 3 meters (10 ft) in height, with both closed and open canopies. Minimum ground cover is 10%; conversion to forest occurs at 35% canopy coverage provided the trees are > 3 m in height. Areas of forest that have experienced burning (burn scars) are classified in this category.
4	**Grassland**	Grass and herbaceous areas. Category may include herbaceous wetlands if images are collected during dry season or periods of drought. Land cover types commonly referenced as savanna, open savanna, and woody savanna are included in this category. Areas of grassland and scrub/shrub that have experienced burning (burn scars) are classified in this category.
5	**Barren/Sparsely Vegetated**	Includes sand dunes, desert, rock outcrops, bare soil other than bare agricultural land, and sparsely vegetated areas of grass and shrub. This category includes non-vegetated strip mines and quarries except where covered by development (urban/built-up) or water (water).
6	**Urban/Built-Up**	Cities, towns, wide roads, airports, other developed areas. Areas of non-urban cover within the urban fringe are only separated from the urban category if they exceed 25 ha (500 x 500 m if square or 307 pixels) in size and 2 pixels (58 meters) in width.
7	**Agriculture, Other**	All non-rice agricultural fields, both with crop or fallow; highly managed pastures and haylands (but not grasslands commonly referenced as "rangeland"); complex mosaics of natural vegetation and cropland. Some orchards and tree plantations, such as palm or date plantations, may be included in this category.
8	**Agriculture, Rice**	Paddy agricultural fields, mainly rice, that are seasonally inundated with water. Depending upon the season of acquired imagery, some rice paddies may be included in the "Agriculture, Other" class if the paddies are not flooded.
9	**Wetland, Permanent Herbaceous**	Emergent herbaceous wetlands, as well as other irregularly inundated areas that may not be vegetated, including: mud flats, saltpans, and playas. Vegetated herbaceous wetlands

Category Number	Category Title	Category Description
		may be referenced as “marsh.” Areas commonly referenced as “swamp,” including forested wetlands, are not included in this wetland class. Forested wetlands, with the exception of “Mangrove” are included in one of the forest categories. Areas of burn scar within a wetland are included in this category.
10	**Wetland, Mangrove**	Regularly inundated coastal areas that are covered by mangrove species. Areas of burn scar within a mangrove wetland are included in this category.
11	**Water**	All type of water bodies, including rivers, lakes, reservoirs, ponds, bays, and estuaries. This categorization does not differentiate between these water classes.
12	**Ice/Snow**	Areas covered by permanent or nearly permanent ice and/or snow.
13	**Cloud/Cloud Shadow/No Data**	Areas in which the ground surface is masked by cloud, smoke, or thick haze, or their concurrent shadows. Also includes any area for which no meaningful Thematic Mapper signal is received, e.g., line drops, areas outside of the coverage of the outermost TM image footprint.

GeoCover LC Products

1. Land Cover Raster File with No Minimum Mapping Unit for Full TM Scene in UTM Projection in ERDAS IMAGINE 8.4 Format

This land cover file has not been filtered or processed to a user-specified minimum mapping unit (MMU). Consequently, it will have inherent speckle and noise of raster data categorizations from remotely sensed data. The speckle and noise is removed when this data set is clumped to the user-specified minimum mapping unit. This UNCLUMPED raster file will be an 8-bit ERDAS IMAGINE file with cell values that indicate the land cover codes (see earlier table for these codes). The following figures provide examples of this product. Although this file has not been clumped and eliminated for land cover less than the MMU, it is much less speckled than the raw land cover file from the early date scene. This is because it is derived from the earlier date scene for which the MMU was applied.

3. Land Cover Raster File with a Minimum Mapping Unit for Full TM Scene in UTM Projection in ERDAS IMAGINE 8.4 Format.

This land cover file will be processed to remove much of the speckle and noise associated with land cover categorizations based upon Landsat TM data. The only difference between this file and the previous file is the incorporation of EarthSat’s CLUMP and ELIMINATE routines to generalize the land cover to a user specified minimum mapping unit. EarthSat’s CLUMP routine is used to define the size of all contiguous features with the same land use code. EarthSat’s

ELIMINATE routine removes any contiguous features of the same land use code (with the exception of water) that were smaller in size than the user-specified minimum mapping unit. The predominant land cover surrounding the eliminated clump replaces the areas of small clumps that are eliminated.

4. Bivariate change raster file with a for Full TM Scene in UTM Projection in ERDAS IMAGINE 8.4 Format

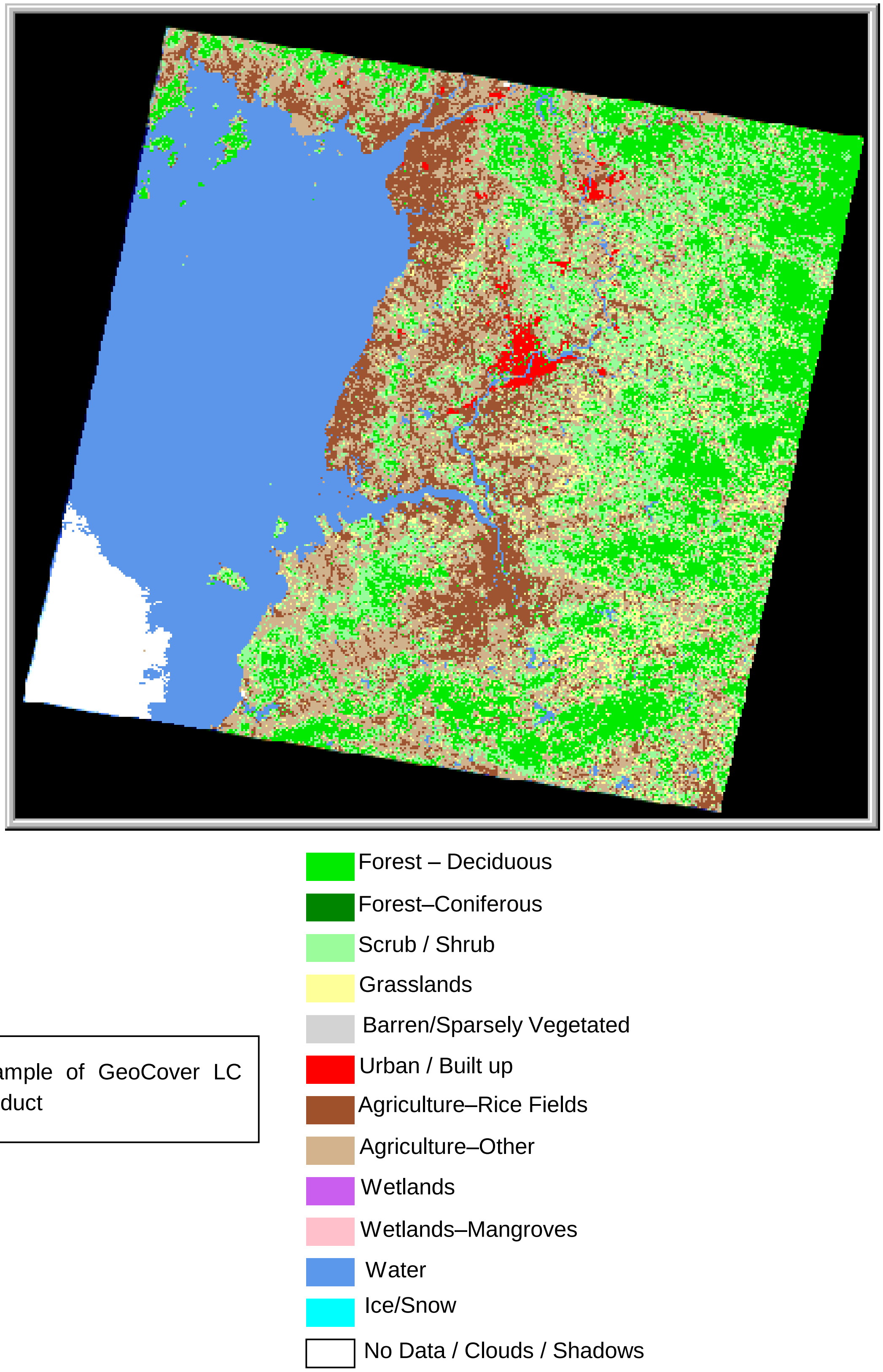
This 8-bit raster file will be also be in UTM projection and will be coded to analyze and display land cover for either the later or more recent epoch. Color table will allow the display to switch rapidly from one epoch to another.

5. Anticipated Schedule

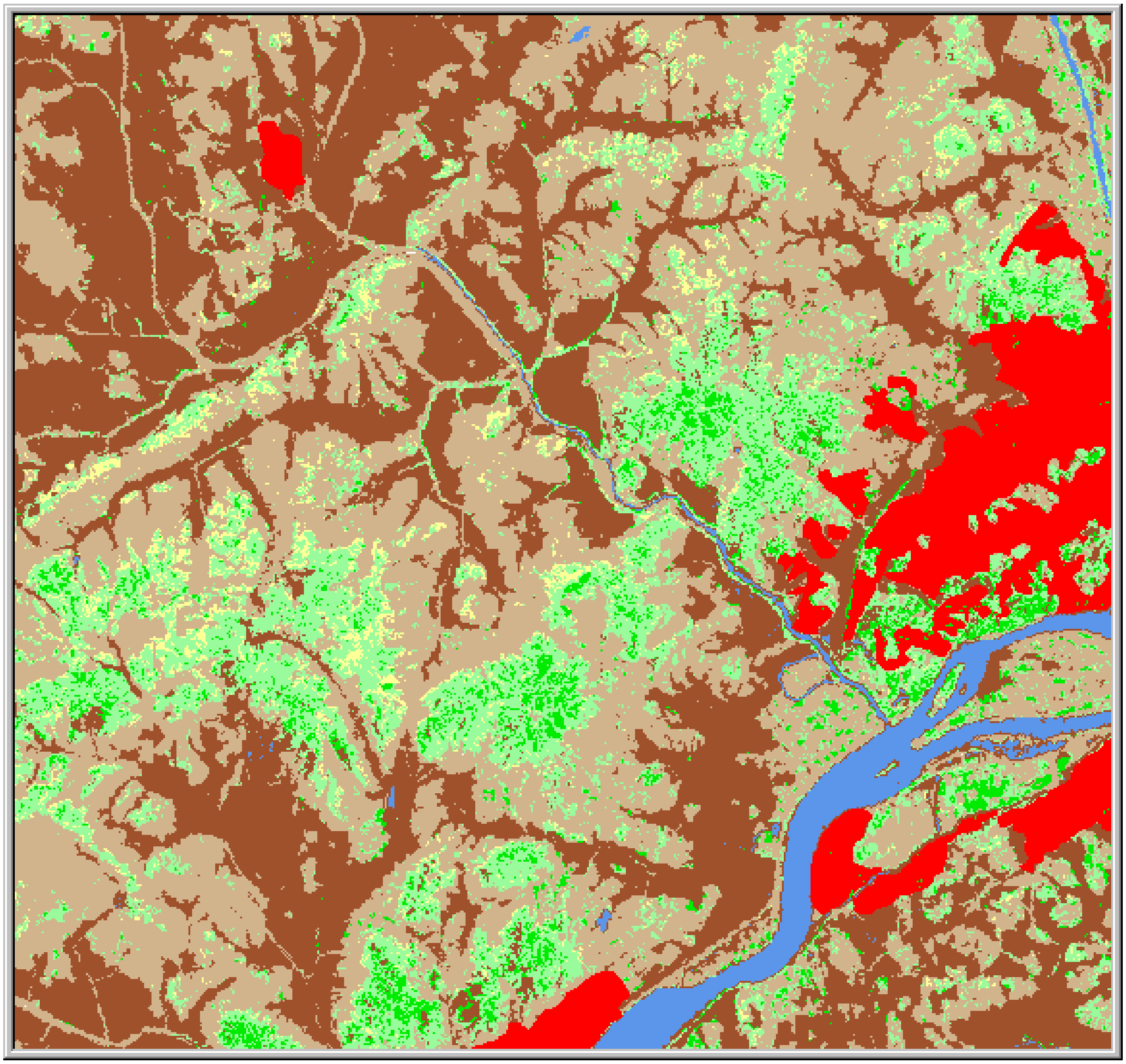
It is anticipated that this project could be completed between 3 to 6 months after the receipt of all the necessary data.

6. Cost

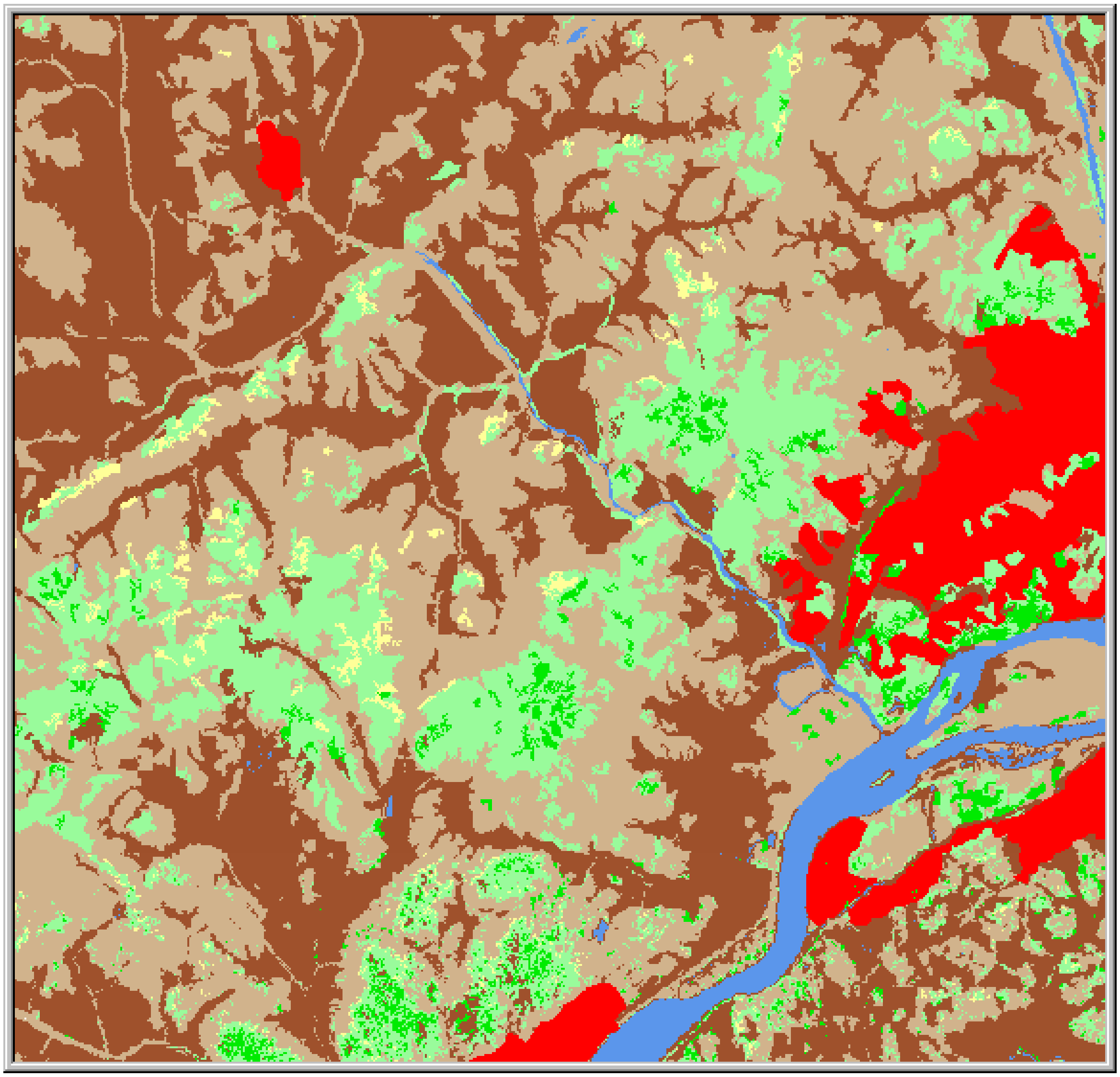
EarthSat’s cost proposal is attached.



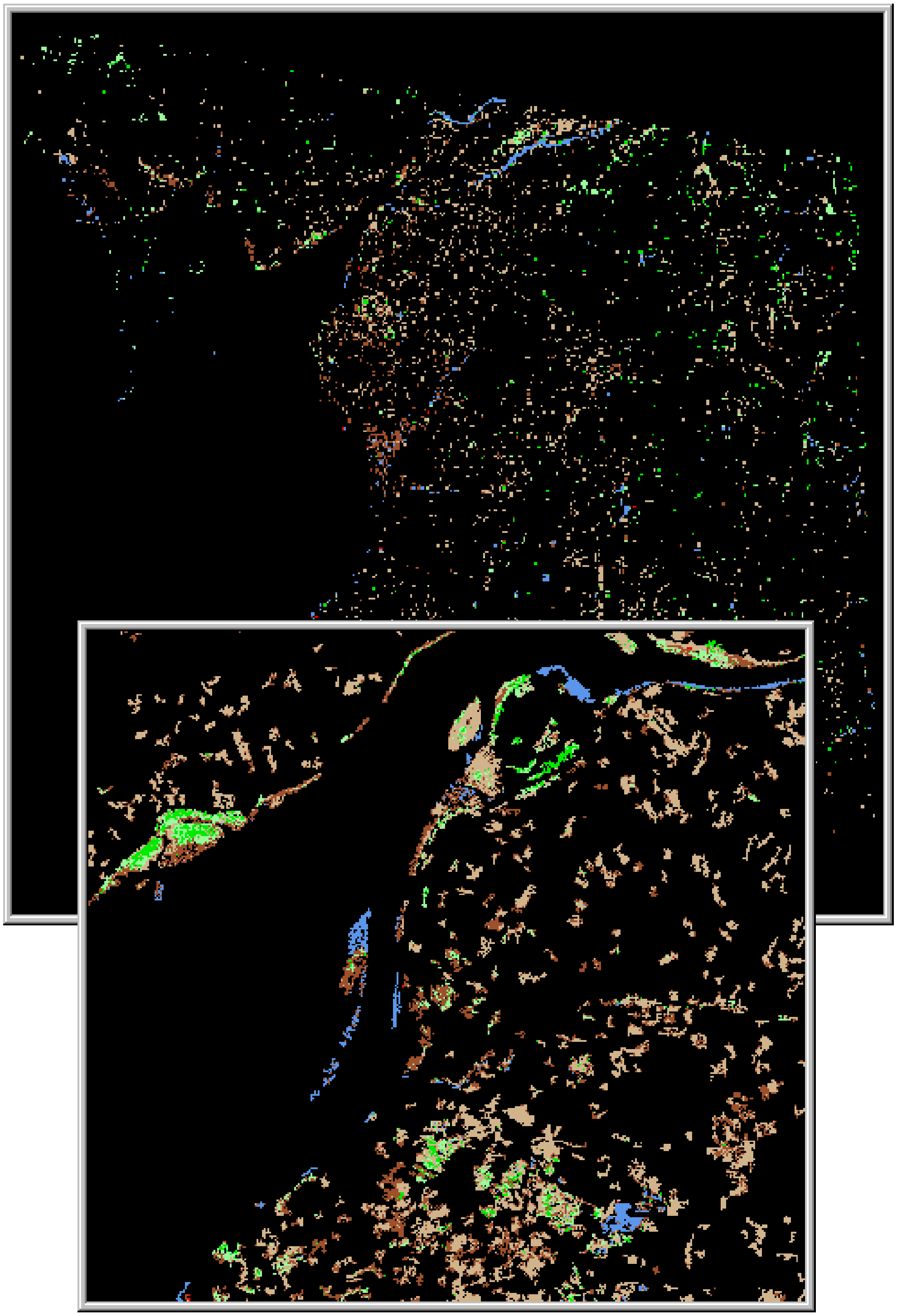
Example of GeoCover LC Product



Example of GeoCover LC product before application of minimum mapping unit.



Example of GeoCover LC product after application of minimum mapping unit.



Example of an updated land cover change image. The CCA Z-statistics file was used to identify areas of change which were then updated to the correct land cover category.

Item	Description	Qty	Price	Price
	Option 1 – Entire Country			
	1970, 1990, 2000 Landsat MSS/Tm coverage for the entire country, with land cover for each time period as wellas land cover change through time.			
1	1970's era Imagrery (landsat MSS Data)	33	$200.00	$6,600.00
	Purchase Historic Archive Imagery	10	$395.00	$3,950.00
	Orthorectify Imagery (1 –10)	23	$325.00	$7,475.00
	Orthorectify Imagery (10 – 33)			
	Subtotals	66		$18,025.00
2	1990 era Imagery (GeoCover Ortho Scenes)			
	1 to 5	5	$200.00	$1,000.00
	6 to 99	28	$125.00	$3,500.00
	Subtotals	33		$4,500.00
3	1990 era Landcover (GeoCover LC Scenes)			
	1 to 5	5	$200.00	$1,000.00
	6 to 20	15	$150.00	$2,250.00
	20 to 49	13	$100.00	$1,300.00
	Subtotals	33		$4,550.00
4	2000 era Imagery (Landsat 7 Data)			
	Purchase Imagery (discount for large order 20%)	33	$480.00	$15,840.00
	Orthorectify Imagery (1 – 10)	10	$395.00	$3,950.00
	Orthorectify Imagery (11 – 33)	23	$325.00	$7,475.00
	Subtotals	66		$27,265.00
5	Cross Correlation Analysis Change Detection from 1970 to 1990	33	$2,500.00	$82,500.00
6	Cross Correlation Analysis Change Detection from 1990 to 2000	33	$2,000.00	$66,000.00
	(Includes $500/scene volume discount)			
	Option 1 Total			$184,815.00

Item	Description	Qty	Price	Price
	Option 2 – 17 Scenes for Area(s) of Interest			
	1970, 1990, 2000 Landsat MSS/Tm coverage for the entire country, with land cover for each time period as wellas land cover change through time.			
1	1970's era Imagrery (landsat MSS Data)	17	$200.00	$6,600.00
	Purchase Historic Archive Imagery	10	$395.00	$3,950.00
	Orthorectify Imagery (1 –10)	7	$325.00	$2,275.00
	Orthorectify Imagery (10 – 33)			
	Subtotals	34		$9,625.00
2	1990 era Imagery (GeoCover Ortho Scenes)			
	1 to 5	5	$200.00	$1,000.00
	6 to 99	12	$125.00	$1,500.00
	Subtotals	17		$2,500.00
3	1990 era Landcover (GeoCover LC Scenes)			
	1 to 5	5	$200.00	$1,000.00
	6 to 20	12	$150.00	$1,800.00
	Subtotals	17		$2,800.00
4	2000 era Imagery (Landsat 7 Data)			
	Purchase Imagery (discount for large order 20%)	17	$600.00	$10,200.00
	Orthorectify Imagery (1 – 10)	10	$395.00	$3,950.00
	Orthorectify Imagery (11 – 33)	7	$325.00	$2,275.00
	Subtotals	34		$16,425.00
5	Cross Correlation Analysis Change Detection from 1970 to 1990	17	$2,500.00	$42,500.00
6	Cross Correlation Analysis Change Detection from 1990 to 2000	17	$2,500.00	$42,500.00
	Option 2 Total			$116,350.00

Item	Description	Qty	Price	Price
	Option 3 – Accuracy Assessment			
	Do in-country fieldwork to validate 2000 land cover, as well as perform an independent accuracy assessment of previous years land cover. Stratified Random Sample of 2000, 1990 and 1980 landcover, approximately 50 points for each class on 17 scenes = 33,150 points (3 daytes x 50 points x 13 classes x 17 scenes)			
1	Review each point 2.5 minutes = 1,381 hours			
	Senior Scientist	40	$120.00	$4,800.00
	Staff Scientist	1,381	$60.00	$82,860.00
	Accuracy Assessment Report			
	Senior Scientist	80	$120.00	$9,600.00
	Staff Scientist	80	$60.00	$4,800.00
	Subtotal			$102,060.00
2	In-country field work			
	Project Manager	160	$180.00	$28,800.00
	Staff Scientist	160	$70.00	$11,200.00
	Airfare	2	$6,000.00	$12,000.00
	Lodging and meals + incidentals (government rate)	28	$340.00	$9,520.00
	Transportation	28	$200.00	$5,600.00
	G and A Direct Costs			$5,424.00
	Cost of In-Country fieldwork			$72,544.00
	Option 3 Total			$174,604.00

Anticipated Schedule

It is anticipated that this project could be completed between 3 to 6 months after the recipt of all the necessary data.